Electroweak Prospects for Tevatron RunII

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The prospects of precision electroweak measurements from CDF and D0 using RunII data is reviewed.

1. Introduction

In RunI each experiment collected about 100 pb^{-1} of data. During RunIIa, each experiment is expected to collect about 2 fb^{-1} of data. The center-of-mass energy for RunII, $\sqrt{s} = 2.0$ TeV, is a bit larger than the 1.8 TeV of RunI and results in an increase of about 10% (35%) in the production cross-sections for W and Z ($t\bar{t}$) events. Additional gains in the event yield are expected due to improvements in the detector acceptance and performance. Taken together, the RunIIa upgrades are expected to yield 2300k (800) W ($t\bar{t}$) events per experiement, including the effects of event selection and triggering, which can be compared to the RunI yields of 77k (20) events. With the RunI data-set, CDF and D0 produced a breadth of electroweak results and obtained the world's only sample of top quarks. While the RunII electroweak physics program is very similar, the RunII upgrade improvements should yield many precision results.

The Tevatron began delivering steady data in about June, 2001. The first six months of data taking was "commissioning dominated" for CDF and D0. Starting around January, 2002, the experiments were largely commissioned and began taking "analysis quality" data. The physics results reported at this conference are based on about $10-20pb^{-1}$ (depending on the data-set) per experiment. Thus, the presently available event samples are smaller than those available in RunI. At this early stage of RunII, it is interesting to compare the present detector performance to that assumed when making the RunII physics projections.

In the following sections I discuss some RunII projections for a few electroweak measurements of particular importance, namely the precision determinations of the W-boson mass, M_W, and the top-quark mass, M_t.

2. Precision Measurement of the W-Boson Mass

In RunI, CDF and D0 each measured the W-Boson mass with an uncertainty of about 80 MeV, which together yield a combined Tevatron result of 80.456 ± 0.059 GeV [1]. For comparison, the (preliminary) LEP combined result is 80.447 ± 0.042 GeV [2].

At the Tevatron the W-bosons are produced by hard collisions between the constituent (anti-)quarks of the proton and anti-proton. Thus, the center-of-mass energy for this hard collision cannot be known *a priori* event-by-event. As a consequence of this, only the constraints in the transverse plane remain. Due to overwhelming QCD backgrounds, only leptonically decaying Ws are used. The W-boson mass can be extracted from a fit to the transverse mass, $M_T = \sqrt{(E_T^{\ell} + E_T^{\nu})^2 - (\overline{P}_T^{\ell} + \overline{P}_T^{\nu})^2}$. It is obvious that a detailed understanding of the energy and momentum scales and resolutions is fundamental to this measurement. In order to accurately estimate the neutrino momentum, it is additionally important to have a detailed understanding of the underlying event and recoil distributions. Finally, since the shape of the M_T distribution is affected by the parton-distribution-functions (PDFs), there is a model-dependent systematic uncertainty associated with this method. For a detailed discussion of these measurements, see references [1] and [3].

The sources of uncertainty in the combined

Table 1

Uncertainties in the CDF/D0 combined M_W measurement. The contribution of each systematic source is approximate.

Source	ΔM_W (MeV)
Statistical:	± 40
Systematic	
scale:	$\pm 40^\dagger$
recoil:	$\pm 20^\dagger$
modeling:	$\pm 15^*$
other:	$\pm 15^\dagger$
total:	± 43

$\dagger$ dominated by statistics of control sample.
$*$ correlated between experiments.

Tevatron M_W determination are given in Table 1. The "other" category includes uncertainties from background shape and normalization and residual fit biases. As is evidenced in the Table, even the Tevatron combined measurement is dominated by uncertainties which are expected to scale with the statistics of the relevant data-sets. The only exceptions to this are the "modeling" uncertainties, dominated by contributions from PDF uncertainties, but also including contributions from higher-order radiative corrections. As these are the only sources of correlated uncertainties between the experiments, they may well come to limit the ultimate precision with which M_W can be determined at the Tevatron. Assuming no improvement in these modeling uncertainties (*i.e.* a conservative assumption), it is rather straight- forward to appropriately scale the other uncertainties to arrive at a projection of $\Delta M_W(2\,\mathrm{fb}^{-1}) = \pm 30\,\mathrm{MeV}$ per experiment and a Tevatron combined uncertainty of about $25\,\mathrm{MeV}$. The only important caveat in this projection is the assumed resolution on P_T^ν, which degrades with the mean number of additional interactions per event. This functional dependence was studied using RunI data. Although the RunIIa instantaneous luminosity increases, the mean number of additional interactions per event is comparable to that of RunI because the Tevatron is running with more bunches. Thus, for the RunIIa projection, this assumption is on fairly solid footing.

Finally, depending on the evolution of the combined LEP uncertainty, and assuming the LEP and Tevatron measurements are completely uncorrelated, this gives an expected world average of $\Delta M_W(\mathrm{LEPII} + \mathrm{TeVIIa}) = \pm 15 - 20\,\mathrm{MeV}$.

3. Precision Measurement of the Top-Quark Mass

In RunI, CDF and D0 each measured the top-quark mass with an uncertainty of about 7 GeV, which together yield a combined Tevatron result of 174.3 ± 5.1 GeV [4].

At the Tevatron, top quarks are predominantly pair-produced, with each top quark predominantly decaying to a W and a b quark. The final-state topology is determined by the decay of the two Ws, with the "di-lepton", "lepton plus jets" and "fully hadronic" final states corresponding to both, one, or neither of the Ws decaying leptonically, respectively. While the di-lepton final state is the most pure, it's branching ratio is smallest (owing to the $BR(W \to \ell\nu)^2$ factor) and it's kinematics are under constrained (owing to the two neutrinos). On the other hand, the fully hadronic final state suffers from a large QCD background. Consequently, the most significant channel for the determination of M_t is the lepton-plus-jets channel. The dominant background contributions to this channel are from $W + \geq 4$ jet events, which can be suppressed by requiring that ≥ 1 jet in the event is identified as a b-quark jet ("B-tagged").

The top-quark mass for each candidate event is determined from a kinematic fit which employs momentum constraints and requires that the two W candidates have a mass consistent with the world average M_W, and that the two top quarks have the same mass. In order to perform the fit, jet-parton assignments must be made, thus giving rise to a combinatoric background, which greatly degrades the resolution of the kinematic fit. For lepton-plus-jet events with 0, 1 or 2 B-tagged jets, there are 12, 6 or 2 possible jet-parton combinations. Thus, the single most important factor in improving the M_t determination for RunII, is the expected improvement in the B-tagging performance, which should yield a more efficient and pure event selection, and should reduce the combinatoric background, effectively enhancing the per event M_t sensitivity. For a detailed discussion of these measurements, see references [4] and [5].

The sources of uncertainty in the "typical" RunI M_t determination are given in Table 2. The "other" category includes uncertainties from background shape and normalization and residual fit biases. The "modeling" uncertainties are dominated by contributions from hadronization and fragmentation modeling, and modeling of final state gluon radiation and are the only source of correlated uncertainty between the experiments. The dominant systematic uncertainty is due to uncertainties in the jet energy scale and associated corrections, which, in RunI, were determined from low statistics control samples. For 2 fb^{-1} of RunII data, the statistical uncertainty is expected to be < 1 GeV per experiment and the measurements are expected to be systematic limited. The RunIIa projections assume that the total systematic uncertainties can be reduced to the $2-3$ GeV per experiment. Reducing the systematic uncertainty to that level will require the use of special control samples ($Z+$ jets, $Z \rightarrow b\bar{b}$, and $W \rightarrow q\bar{q}$) which, in general, were too small to be of use in RunI. Thus, the RunII projections have been based on detailed Monte Carlo simulations of these data-sets. The efficiency and purity with which many of these controls samples are collected are contingent upon the performance of the silicon vertex detectors. There have not been, to the author's knowledge, any

detailed study to estimate the projected Tevatron combined M_t uncertainty after 2 fb^{-1} of data. Obviously the projection is strongly dependent upon the assumed evolution of the modeling uncertainty. The most conservative projection would assume no improvement, so that each experiment would have a measurement uncertainty dominated by these modeling uncertainties. In that scenario, the combination would yield very little improvement over the $2-3$ GeV uncertainty per experiment.

4. Initial Detector Performance

The CDF and D0 detector upgrades have been described many times and the details are available in references [6] [7]. It is principally important to note that the RunII electroweak projections assume i) the energy and momentum resolutions are no worse than those of RunI, ii) B-jet and lepton[1] identification are extended to the $|\eta| > 1$ forward regions [2], and iii) the trigger performance allows efficient collection of the relevant samples up to instantaneous luminosities of about 2×10^{32}cm^{-2}sec^{-1}. The performance of the relevant detector components is briefly discussed here.

Both CDF and D0 upgrades include silicon micro-strip detectors at inner radii, surrounded by large volume tracking chambers, all inside a magnetic field. Both experiements have finished initial alignments of their silicon detectors and are measuring high signal-to-noise ratios (≥ 12) with the expected intrinsic resolution and high hit efficiency ($\geq 98\%$). This bodes well for the B-tag performance of the two experiments. Both experiments have also collected large statistics samples of $J/\Psi \rightarrow \mu\mu$ events, which are used to perform a variety of systematic studies to limit residual mis-

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[1] Through the whole of this note, it should be understood that "lepton" means an electron or a muon, unless otherwise stated.

[2] The co-ordinate system has the z-axis parallel to the beam-axis and pointing in the proton flight direction, the x-axis orthogonal to the z-axis and pointing to the center of the Tevatron, and the y-axis defined to yield a right-handed co-ordinate system; the angles θ and ϕ are the traditionally defined polar and azimuth spherical coordinates, respectively, and the pseudo-rapidity, η, is defined as $\eta = -\ln(\tan(\theta/2))$.

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Table 2
"Typical" per experiment uncertainties in the RunI M_t measurement.

Source	ΔM_t (GeV)
Statistical:	±5
Systematic	
scale:	±4
modeling:	±2*
other:	±2
total:	±5

∗ correlated between experiments.

alignments, and determine energy-loss and B-field corrections. Although still at an early stage, the present P_T resolution for CDF's COT is better than $\sigma_{P_T}/P_T^2 < 0.13\% \, \text{GeV}^{-1}$, comparable to the 0.10% design goal [8]; this is expected to improve as the alignment matures. Similarly, D0 expects the CFT to meet design goals once alignment and calibrations are finalized.

Since both experiments left their calorimetry largely unchanged relative to RunI (CDF replaced their forward calorimetry), the resolution should be well understood. The observed width of the invariant mass spectrum in $Z \rightarrow e^- e^+$ events can be used to estimate this resolution. Including all major corrections for both the forward and central calorimeters, CDF observes a width within 5% of that expected [9]. At the time of the conference, D0 had not yet included the full set of corrections and, consequently, were observing a width 30% larger than expected; this is roughly consistent with the contribution expected from the excluded corrections.

Despite some initial problems, both experiments have demonstrated their ability to efficiently trigger on events of interest. CDF has measured a Level 1 tracking efficiency > 95% (important for triggering on high-momentum leptons) and D0 showed similarly high effiencies for high-momentum electrons. CDF has also collected large samples enriched in heavy-flavor (c- and b-quark jets) by use of a displaced track trigger at Level 2 (SVT) - the first such trigger at a hadron collider [10]. This is an important first step in accumulating the $Z \rightarrow b\bar{b}$ control sample mentioned above.

Although it is still a bit early to draw any definitive conclusions, both the CDF and D0 detectors look to be on track to meet their design goals and fulfill the RunIIa Electroweak physics projections.

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